

**ENGINEERING SUSTAINABILITY & SUSTAINABLE ENERGY 2018  
(ESSE '18) CONFERENCE**Tuesday 8<sup>th</sup> May 2018, Dolmen Resort Hotel & Spa, St. Paul's Bay, Malta

ISBN: 978-99957-853-2-1

**EXPERIMENTAL PERFORMANCE OF A DUAL-SOURCE HEAT PUMP COUPLED WITH SHALLOW  
HORIZONTAL GROUND HEAT EXCHANGERS**M. Cannistraro<sup>1</sup>, E. Mainardi<sup>2</sup>, M. Bottarelli<sup>1</sup><sup>1</sup>Department of Architecture, University of Ferrara, Via Quartieri 8, Ferrara 44121, Italy

Tel: (+39) 0532 293662

Corresponding Author E-mail: [mauro.cannistraro@unife.it](mailto:mauro.cannistraro@unife.it)<sup>2</sup>Department of Engineering, University of Ferrara, Via Saragat 1, Ferrara 44124, Italy

**ABSTRACT:** The present paper analyses the preliminary results about the performance of a dual-source heat pump (DSHP), able to switch between air and ground according to operating rules for the air-conditioning system. The prototype is composed by a common air-to-air heat pump whose refrigerant circuit has been modified for coupling through a plate heat exchanger with a geothermal closed loop, laid horizontally and edgewise into a shallow trench. As ground heat exchanger (GHE), the Flat-Panel solution has been chosen due to its higher performance in comparison with similar GHEs, that makes this solution suitable for the issue. To over/underload the GHE system according the air conditioning energy load, the closed loop can be reduced by means of valves. The switching between air and ground is then automatized with a control unit which controls valves according to rules based on air and ground temperature, air humidity, and frosting conditions at the evaporator. The prototype is fully monitored in terms of temperatures, pressures, flow rate and electricity supply, both at the refrigerant circuit and the closed loop. Moreover, a dedicated monitoring system collects data about weather conditions, ground temperature at several depths and distances from the Flat-Panels, and finally their heat flux. The heating performance of the DSHP is taken in comparison with the standard air-source solution, with evidence of the better behaviour, even for a closed loop drastically partialized.

**Keywords:** *Dual-Source Heat Pump, Horizontal Ground Heat Exchangers, Flat-Panel, Operating Rules*

## 1 INTRODUCTION

European Community is facing challenge in terms of energy improvement and aims to promote policies to boost up to 20% the use of renewable resources within 2020, as indicated in the last EPBD [1]. Among them, reversible air source heat pumps (ASHPs) and ground coupled heat pumps (GCHPs) are regarded as viable and efficient technologies for space cooling and heating of residential and commercial buildings. They are an ecological alternative to traditional heating [2], able to reduce the harmful emissions in atmosphere as they use renewable energy sources, such as air, water and ground, extracting/rejecting the heat from themselves. Although ASHPs have universal applicability and versatility, the energy performance may be affected not only by the outdoor air temperature, but also by the air humidity as well. When the air moisture content is high and the temperature lower than 3-4°C, the frosting of the airside heat exchanger (fin & tube evaporator) may occur and consequently the heat pump performance can be drastically reduced up to the stopping of the

system for defrosting [3].

On the other side, GCHPs are used especially for profitable and stable thermal conditions in exploiting the ground as thermal source/sink which can reduce significantly the fluctuation of the temperature. Nowadays, two types of ground heat exchangers are widespread: vertical (VGHEs) and horizontal (HGHEs) ground heat exchangers. VGHEs have higher efficiency but higher purchase and installation cost, whereas HGHEs [4] are inexpensive in term of arrangement and more compliant with environment regulations, but affected by drawbacks for land area requirement and lower efficiency due to less stable thermal condition in very shallow ground. Recently, novel shapes [5] of HGHEs have been proposed to reduce these drawbacks, such as baskets, tapes, spiral-tube, and so on. Especially, the Flat-Panel (FP) developed by University of Ferrara (European Patent pending n° EP11177528.4) shows very high performance when compared with all other solutions [6].

The widespread ASHPs are significantly affected by the operating condition whereas the GCHPs have

a limited diffusion due to the installation costs.

New trends and developments in ground-source heat pumps lead researchers in thermal field to study new applications for overcome the issues due to latter technologies. Following up numerical study based on the performance [7] and sizing [8] of the FP compared to the traditional shallow ground heat exchangers, an efficient and advanced hybrid air-ground heat pump system (so-called dual-source heat pump, DSHP) has been designed and installed at University of Ferrara supported by European fund program POR-FESR 2014-2020. A DSHP [9] could be an effective solution to solve the previous issues, as joining the performance of air source and ground source in a stand-alone system able to switch to the most favourable working conditions. It could grant significant energy saving due to better thermal properties of ground source, its higher stability and its more favourable temperature patterns. By the other side, the size of ground heat exchanger could be considerably reduced for a DSHP, according to the lower thermal energy exchanged with the ground if compared with a full GCHP configuration.

This study aims to evaluate the preliminary performance of a real setting of DSHP and its potential benefits over traditional ASHP and GSHP [6]. The analysis is carried out experimentally, as first step of future studies.



**Figure 1:** Plant location

## 2 TESTING FACILITY

The facility is operating at the TekneHub (N44.831, E11.599), which is a laboratory of the University of Ferrara belonging to the high technology network of the Emilia-Romagna region (Fig. 1). The local climate is usually referred to a

continental climate. The winter is harsh and humid, and the temperature often decreases below  $0^{\circ}\text{C}$  (2326 heating degree days). The summer is hot and muggy, with a daily temperature often higher than  $35^{\circ}\text{C}$ . Therefore, even if it is a World Heritage site stated by UNESCO, Ferrara does not bet on its weather. The facility is composed by a building air-conditioned with the novel DSHP, coupled with a geothermal closed loop installed in the back yard (Fig.2). The DSHP is controlled by a PLC and a comprehensive monitoring system collects data of the HVAC, ground and the weather.

### 2.1 The building

A one-storey small building composed by two rooms has been devoted for testing, since a room has been air-conditioned with the novel DSHP (volume of  $48\text{ m}^3$ , net floor  $16\text{ m}^2$ ). The external walls are made of bricks with a polystyrene thermal insulation layer (calculated U-value of  $0.21\text{ W/m}^2\text{K}$ ). The roof is built with predalles precast roof slabs with 160 mm of polystyrene thermal insulation layer (U-value of  $0.20\text{ W/m}^2\text{K}$ ). The floor consists of an insulated light concrete layer supported by a structural concrete aired slab and a concrete sub-foundation (U-value of  $0.24\text{ W/m}^2\text{K}$ ). Finally,  $6.5\text{ m}^2$  of opening windows are present at the west side (U-value of  $1.9\text{ W/m}^2\text{K}$ ).



**Figure 2:** Flat-Panel trench laying

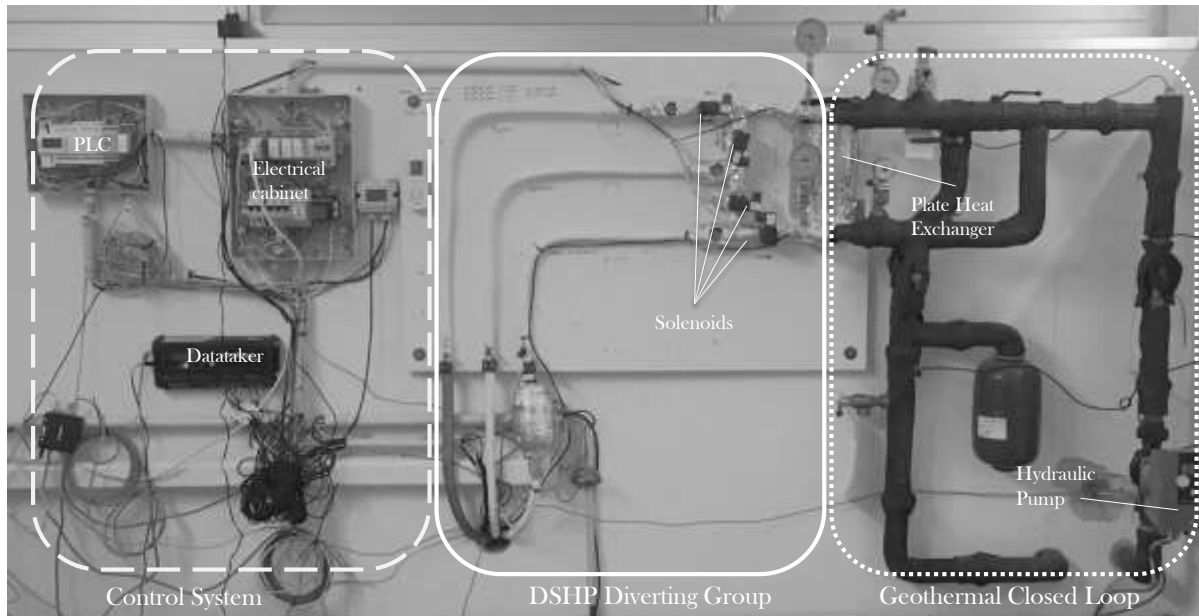
### 2.2 The dual-source heat pump system

A commercial air source heat pump has been modified to be coupled with a geothermal closed loop via a plate heat exchanger (Fig. 3). As a consequence, the refrigerant piping has been modified to bypass the fin and tube air heat exchanger. In detail, a traditional reversible ( $2.5\text{ kW}$ ) air to air heat pump has been properly modified. The selected heat pump employs R410A as refrigerant fluid and consists of one outdoor

unit with rotary inverter compressor and a variable speed indoor unit. In the Fig.3, a section of the built-in copper piping of the experimental setup is shown, as redesigned and stretched to allow a new configuration of heat pump system able to divert the working fluid by means of solenoid valves between the two exchangers according to the signals provided by the PLC. Therefore, DSHP can operate with the air heat exchanger (air mode), the GHEs (ground mode), otherwise mixing previous solutions as well (mix mode). To reduce electric consumption caused by the external fan and avoid frosting, a three phase cut-on is able to turn off it as necessary. The iteration and checking process is managed by means of a programmable logic controller (PLC) which allows to switch between the two sources under certain conditions. A complete on board monitoring system has been installed for control and further assessment of the DSHP and soil temperature field alteration.

### 2.3 The automation system

The behaviour of the DSHP is managed by means of a programmable logic controller (PLC), which is able to switch between the two sources (air/ground), based on several conditions. The PLC reads continuously data from several sensors (temperature, pressure, ice presence, ...) and drives four solenoid valves to modify the piping according to its control algorithm. It is also equipped with a Modbus unit, used to establish a control net with a few devices (energy meters, external temperature and humidity unit, hydraulic pump) and a web server. This latter has been used to implement a web human machine interface (HMI) which allows the remote changing of several set points that affect the PLC decisions (temperature thresholds, timings, hydraulic pump speed, turning on and off the fan etc.). Data are saved in Ascii files and are available for further processing.



**Figure 3:** Detail of the experimental setup

At the moment, three different operating modes are implemented in the control algorithm:

- Automatic: the source switching is automatically controlled by the PLC which refers to a parameter set fixed by the user. Parameters and values tested are summarized in Table 1;
- Manual: this setting is used to manually force a source mode;
- Testing: a debug mode to control reliability of each added reference parameter

**Table 1:** Switching control parameters

| Index        | Parameters   | Winter | Summer | Unit |
|--------------|--|--------|--------|------|
| $T_{dual}$   | Air temperature for dual functionality                                     | <5     | >35    | °C   |
| $T_{wat\_r}$ | Temperature range for operating in ground mode                             | -2     | 30     | °C   |
| $\Delta T$   | Temperature difference between ground and air for switching in ground mode | 0:7    | -7:0   | °C   |
| $t_{air}$    | Shortest time in air mode before switching                                 | 5      | 5      | min  |
| $t_{wat}$    | Shortest time in ground mode before switching                              | 15     | 15     | min  |
| Ice          | Defrost control switching  | flag   | -      | -    |

#### 2.4 The geothermal closed loop

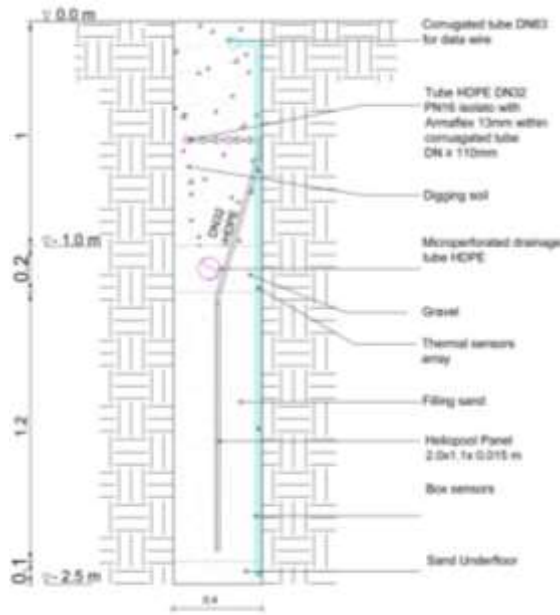
The geothermal closed loop is made up of three pairs of FPs, each one 2.0 m long, 1.1 m high and with an internal cavity of 0.017 m wide, thus performing a hollow volume of 30 Lt. As detailed in Figure 4, the FPs have been edgewise buried in a trench 2.5 m deep and 0.4 m wide, backfilled with washed sand. A gravel layer with a dedicated irrigation system has been laid at the top to soak the trench on demand and improve soil thermal performance. For covering, it has been used soil originated from digging. The thermo-physical ground properties are listed in Tab. 2, as professionally characterized at the Istanbul Technical University.

The main hydraulic loop depicted in Figure 5 is composed by 25 meters of insulated DN20 HDPE as main collector, a hydraulic pump, and an expansion vessel; four valve groups allow to partialize the piping, so that every pair of FPs can work alone or in series mode, on demand. Finally, a plate heat exchanger installed in the experimental room performs the heat transfer between brine and refrigerant, in parallel or counter flow according to specific valves state.

To avoid icing of the geothermal closed loop caused by the drop of temperature of brine passing through Flat-Panel, it was added 30 % of glycol to exploit the system till -15 °C.

**Table 2:** Thermo-physical soil properties.

| Material | Thermal cond.<br>(W/m·K) | Density<br>(Kg/m <sup>3</sup> ) | Specific heat<br>(kJ/Kg·K) |
|----------|--------------------------|---------------------------------|----------------------------|
| Sand     | 2.75                     | 2100                            | 0.88-1.1                   |
| Clay     | 1.52                     | 1860                            | 0.92-1.4                   |

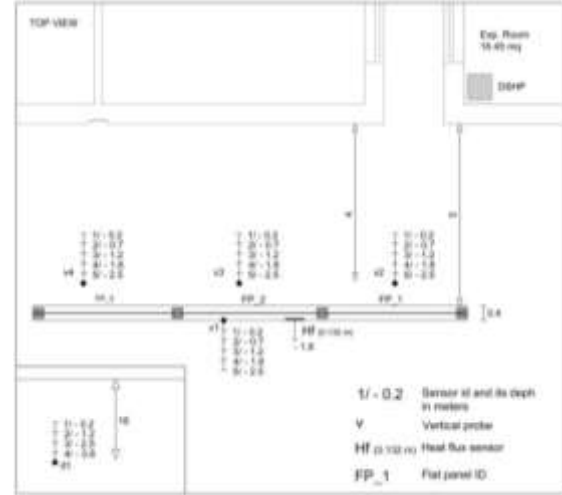


**Figure 4:** Cross section of Flat-Panel and probe

#### 2.5 The monitoring system

As summarised in Table 3, more than 50 sensors split in four different data collecting systems have

been installed to control the experimental prototype and to monitor its performance (Multiplex SGM-Lektra, Datalogger DataTaker, Eliwell PLC, Davis weather station).



**Figure 5:** Plant of the geothermal loop and probes

In ground (Figures 4 and 5), a first sensor group of vertical line probes is digged inside and outside the trench at different depths, in order to measure the ground temperature. Then, a thermal heat flux sensor installed 13 cm away and in front at the FP allows to evaluate the heat flux. A second sensors group monitors the temperatures and pressures of the HVAC system in all relevant piping sections. Furtherly, a third group of sensors is deputed to acquire data via PLC in order to evaluate the brine temperature and flow rate.

**Table 3:** Sensors array installed

| Obj         | Parameter         | Section                               | Unit             | N  | System    |
|-------------|-------------------|---------------------------------------|------------------|----|-----------|
| Soil        | Temperature       | Vertical probe group inside trench    | °C               | 5  | Multiplex |
|             | Temperature       | Vertical probe group 1m far from FP   | °C               | 15 | Multiplex |
|             | Temperature       | Undisturbed soil vertical probe group | °C               | 4  | Davis     |
|             | Heat flux         | 13 cm away from Flat-Panel            | W/m <sup>2</sup> | 1  | DataTaker |
| HVAC        | Temperature       | Heat pump piping                      | °C               | 10 | DataTaker |
|             | Energy            | Heat pump                             | kW               | 1  | PLC       |
|             | Ice presence      | Fin tube (air heat exchanger)         | S/m              | 1  | PLC       |
|             | Pressure          | Heat pump piping                      | bar              | 3  | PLC       |
|             | Temperature       | Indoor/outdoor                        | °C               | 2  | PLC       |
|             | Temperature       | Output air heat exchanger             | °C               | 2  | PLC       |
|             | Relative Humidity | Outdoor                               | %                | 1  | PLC       |
|             | Flow rate         | Hydraulic pump                        | l/h              | 1  | Plc       |
| Ground loop | Energy            | Hydraulic pump                        | W                | 1  | Plc       |
|             | Temp.             | Hydraulic piping                      | °C               | 5  | Plc       |



Moreover, electricity supplied to the DSHP and the circulation pump are monitored by means of two single energy meters. Finally, the ice forming on the external fins of air heat exchanger is detected by means of a leaf-wetness sensor. The ice sensor is able to sense different electrical conductivity of air, water and ice therefore supporting the bypass from air to ground.

### 3 START UP AND PRELIMINARY RESULT

The system has been started for the first time on January 2017, but several changes have been performed to improve the overall efficiency affected by a pressure drop due to piping size added to the heat pump (around 1 bar). To overcome these issues, the section was redesigned by enlarging the pipe cross section and by simplifying the piping refrigerant loop. Moreover, to equilibrate the remaining gas pressure drops between the two different paths (compressor to fin and tube air exchanger; compressor to plate heat exchanger), a calibration valve was also added at the inlet of air heat exchanger.

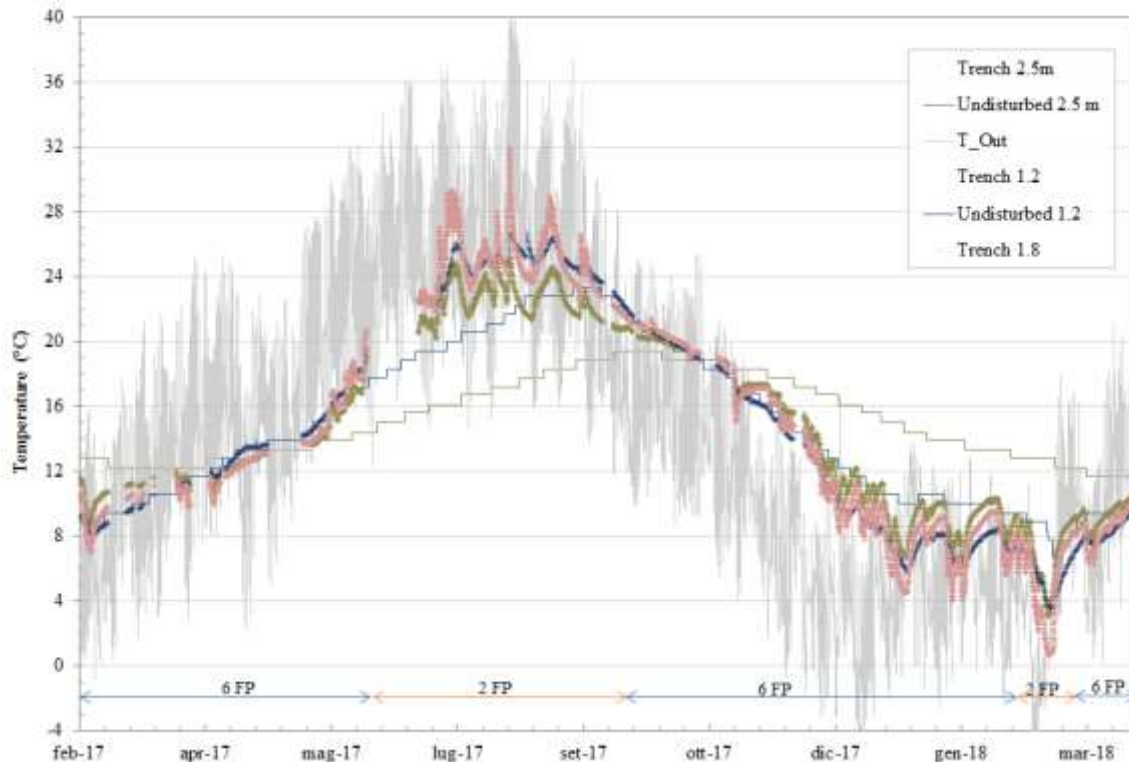
The operation was tested in different working conditions, with different number of FPs, flow rate and periods (Table 4).

In Fig. 6, the yearly ground temperature caused by the FPs is shown in comparison to the unaltered temperature of the soil. These temperatures are

referred to the probes sited at different depths respectively at the top (blue line 1.2m), at the bottom (green line 2.5m) and in the middle (orange line 1.8 m) of the FPs. Higher peaks occur due to the exploitation of two groups of FP and intensive work of DSHP during the tests in several conditions. Either bottom and top line show a variation regarding unaltered lines about 6-8°C, and more than 10 degrees using the line corresponding to the FP as a reference. Less than ten days are enough to recover every alteration of the soil temperature, also including the involved domain 1m far by the FP. Three FP groups have been fully suitable to meet the overall heating and cooling load needed; nevertheless two groups of FPs are still satisfactory using the imposed working rules on the control system.

**Table 4:** Operation period monitoring

|  | 1 <sup>st</sup> period |             | 2 <sup>st</sup> period |
|--|------------------------|-------------|------------------------|
|  | Winter                 | Summer      | Winter                 |
| <b>Start time</b>  | 13 Feb 2017            | 15 May 2017 | 10 Oct 2017            |
| <b>End time</b>  | 15 May 2017            | 10 Oct 2017 | ongoing                |
| <b>Ground wetting condition</b>                            | 100%                   | 30%         | 100%                   |
| <b>Brine flow rate, (m<sup>3</sup>h<sup>-1</sup>)</b>      | 0.417                  | 0.417       | 0.417                  |
| <b>Indoor air flow rate, (m<sup>3</sup>h<sup>-1</sup>)</b> | 380                    | 380         | 380                    |
| <b>Setpoint, °C</b>  | 20-23                  | 24-26       | 20-23                  |



**Figure 6:** Yearly average temperature of the ground

The number of FP employed has been changed to test different conditions and assess the overall length of the GHEs. Solely one group of two Flat-Panel has been employed to meet the summer period (May to Sept 2017) and winter period (Feb 2018); three group of six FP cover the remaining period.

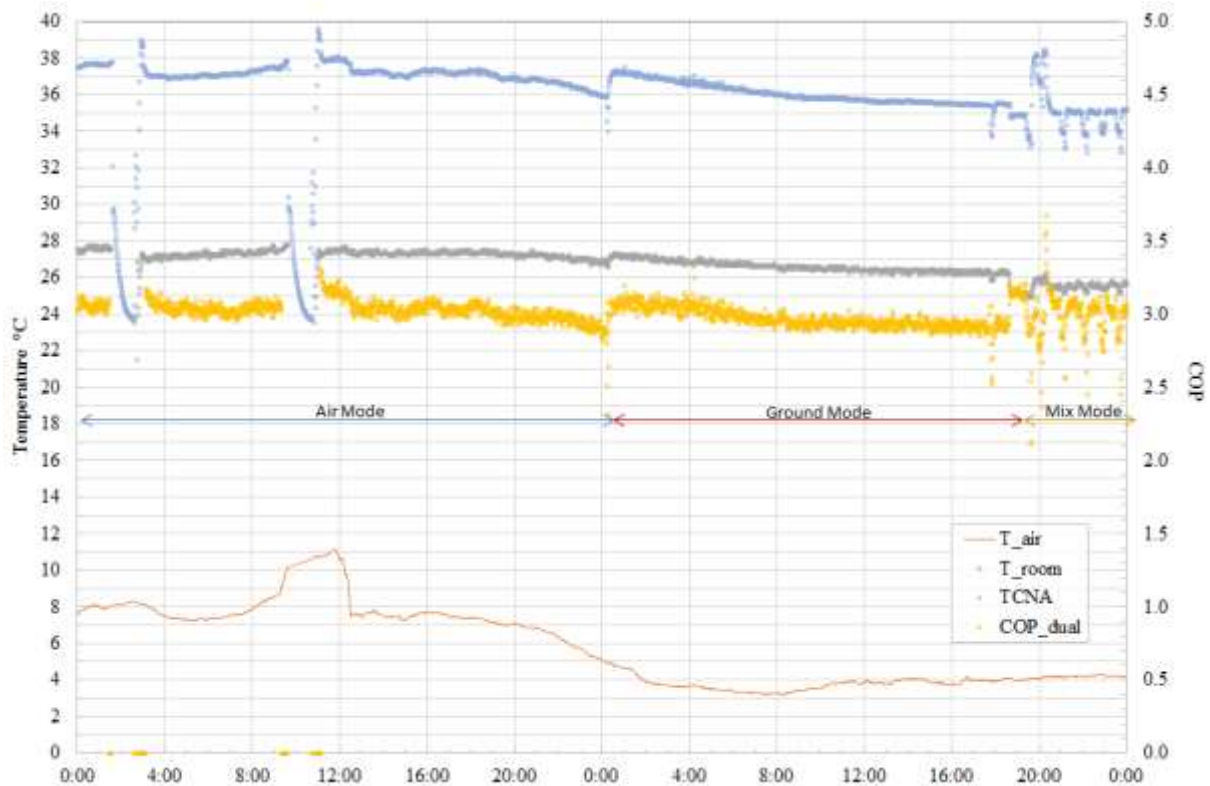
In figure 7, the detailed behaviour of the DSHP is depicted for two days: 18 and 19 March 2018.

The chart shows indoor and outdoor air temperature, outlet temperature from condenser, the coefficient of performance, and the source used by the DSHP. The latter is represented by means of three different colours: blue (air source), red (ground source) and yellow (mix mode). During the monitoring period the outdoor temperature range varies from 11 to 3 °C and the heat pump is free to select the best source according to the imposed parameters. The figure shows that the air COP decreases due to a similar trend of the outside temperature. When the DSHP switches into ground source mode the COP trend line is higher, and the air temperature at the condenser too. It is also notable the difference in indoor temperature when the working mode changes between the two sources; higher values of indoor temperature during ground source mode respect to the same temperature in air source mode.

The gain of the ground source in terms of COP is 10% higher than air source mode and drastically higher with lower temperature. Last period represents a period of mixing due to the imposed setting parameters which allows continuous switching between the two best sources.

#### 4 CONCLUSION

This study has analysed the thermal behaviour of the next generation heat pumps which will involve more thermal sources. The experimental test shows that coupling shallow ground heat exchanger, (specifically Flat-Panel) with a modified traditional air source heat pump can be a suitable and profitable solution to improve the overall performance. Dual source heat pump allows more favourable working condition, may decrease the length of the HGHE and therefore can offer an efficient and cost effective solution respect to other widespread expensive solutions. In addition, DSHP can also prevent frosting phenomenon on air heat exchanger by turning on mix mode reducing energy consumption and thermal discomfort due to lowering temperature inside the room. This preliminary tests are promising but further results are to be analysed during summer period.



**Figure 7:** Daily performance of DSHP

## 5 ACKNOWLEDGEMENT

This study has been supported by the European POR-FESR 2014-2020 fund of the region Emilia-Romagna, Italy.

Thanks to Dr. A. Alper Aydın of Istanbul Technical University for the thermo-physical ground analysis.

## 6 REFERENCES

- [1] European Directive 2010/31/EU of the European Parliament and of the council on the energy performance of buildings
- [2] Dongellini M., Naldia C., Morini G.L., Annual performances of reversible air source heat pumps for space conditioning *Energy Procedia* 78 (2015), 1123 – 1128;
- [3] Vocale P., Morini, G. L. and Spiga, M., Influence of outdoor air conditions on the air source heat pumps performance *Energy Procedia*, 45 (2014), 653-662;
- [4] H. Fujii, S. Yamasaki, T. Maehara, T. Ishikami, N. Chou, Numerical Simulation and Sensitivity Study of Double-Layer Slinky-Coil Horizontal Ground Heat Exchangers. *Geothermics*, 47, 61-68, (2013).
- [5] New trends and developments in ground-source heat pumps, book chapter of *Advances in Ground-Source Heat Pump Systems* 13 5 (2016), Pages 359-385;
- [6] Bottarelli, M., A preliminary testing of a flat panel ground heat exchanger *International Journal of Low-Carbon Technologies* 8 2 (2013), 80-87;
- [7] Bottarelli M., Li Zhang, Bortoloni, M., Yuehong Su, Energy performance of a dual air and ground-source heat pump coupled with a Flat-Panel ground heat exchanger, *Bulgarian Chemical Communications*, Volume 48, Special Issue A (pp. 64-70) 2016
- [8] Bortoloni, M., Bottarelli, M., On the sizing of a flat-panel ground heat exchanger, *International Journal of Energy and Environmental Engineering* 6 2 (2015), 185-195;
- [9] Esen, H., Inalli, M., and Esen, M., Numerical and experimental analysis of a horizontal ground-coupled heat pump system, *Building Environ.*, vol. 42(2007), pp. 1126–1134;